Frigate Fuel Consumption Indicator

Final Report

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MARIN

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FRIGATE; FUEL CONSUMPTION INDICATOR

Final Report

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FRIGATE; FUEL CONSUMPTION INDICATOR

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CONTENTS

Page

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1 INTRODUCTION

DRDC Atlantic ordered the Maritime Research Institute Netherlands (MARIN) to perform a study on the hydrodynamic efficiency for frigate/destroyer type of vessels in order to improve their requirements for the allowable fuel consumption. MARIN proposed to evaluate the model test results of about 15/20 frigates from NATO related countries and to present this in dimensionless tables and diagram form.

The report will contain a section describing how the derived data have been obtained from the model test data, including assumptions and other relevant issues.

Based on our business confidentiality agreement with our relations the data of the scatter diagram derived don’t show any reference or particulars vessels, but the ranges of the general parameters such as length, beam, displacement, prismatic coefficient, slenderness ratio, year of testing of the final selected vessels all with twin screw controllable pitch propellers are listed in a table in the next section.

Throughout this report SI units are used unless indicated otherwise, and a list of symbols is given in Appendix I.

2 SELECTION OF SIMILAR VESSELS

From the 22 frigate vessels found in our model database, 11 vessels are selected for evaluation of the model tests full scale trials performance predictions. A list of the main particulars of the vessels is shown in the next table.

Tested	Ship type	Lpp [m]	Los [m]	Taft [m]	Tfore [m]	B [m]	V [m3]	L/B	CM	CB	CP	B/T	SL-ratio
2003	Frigate	110.99	114.60	4.86	4.86	14.81	3625.6	7.49	0.745	0.454	0.609	3.05	7.46
2004	Frigate	118.87	118.95	4.39	4.39	14.80	3828.0	8.03	0.800	0.496	0.620	3.37	7.60
2008	Frigate	103.50	103.79	3.64	3.64	13.03	2380.4	7.94	0.768	0.485	0.631	3.58	7.77
2009	Frigate	139.00	142.88	5.31	5.31	19.20	6341.5	7.24	0.789	0.448	0.568	3.62	7.72
1999	Frigate	133.20	133.40	4.86	4.86	17.52	5602.7	7.60	0.805	0.494	0.614	3.61	7.51
1997	Frigate	132.00	131.82	4.60	4.00	15.21	4461.5	8.68	0.817	0.517	0.633	3.54	8.01
2001	Frigate	130.20	130.57	5.28	4.93	17.13	5665.0	7.60	0.781	0.498	0.638	3.36	7.32
1990	Frigate	114.10	114.34	4.28	4.28	13.11	3146.0	8.70	0.803	0.491	0.612	3.06	7.80
1983	Frigate	122.00	121.98	4.63	4.38	14.79	3941.0	8.25	0.787	0.485	0.617	3.29	7.72
1983	Frigate	126.00	126.00	4.64	4.46	14.80	4092.0	8.51	0.796	0.482	0.606	3.32	7.88
1979	Frigate	126.00	126.00	4.12	4.12	13.60	3443.0	9.26	0.805	0.488	0.606	3.30	8.34

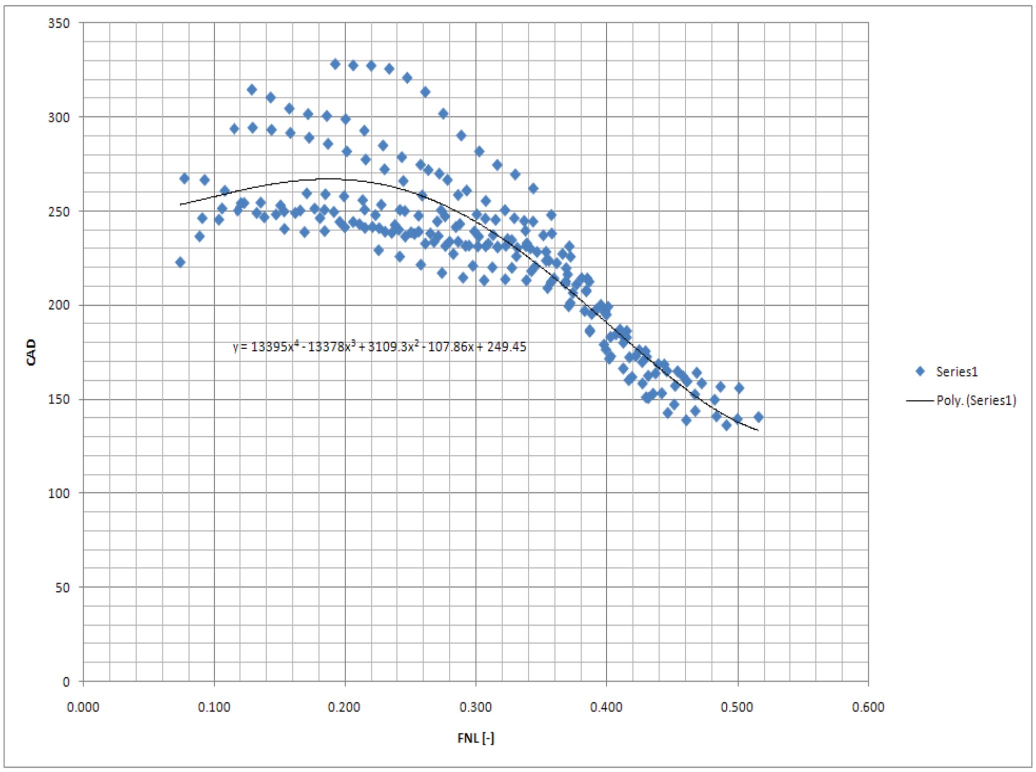
All vessels are equipped with twin screw controllable pitch propellers which satisfy the difficulty index: P-shaft/(V_{design} x D^2) > 25 where PS is the propulsive power per shaft for naval vessels, where D is the propeller diameter in metres and V is the maximum speed of design in knots.

The slenderness-ratio, based on the submerged length (Los) divided by the 1/3 power of the displacement volume (V) of the selected vessel is between 7.4 and 8.5, prismatic coefficient (CP) is around 0.6 and the length between the perpendiculars (Lpp) is between 103.5 and 139 m.

Apart from the application of sonar bulb type bow, keel dome type or no sonar at all, stabiliser fins and intermediate struts configurations, the remaining appendages are quite similar. The aft body however, show more difference when comparing transom immersion, trim wedge application and aft body design; this has more influence on the power requirements in the low speed cruise region around 18 knots than for the combat region around 30 knots speed of ship. The deviation observed (+/- 20 per cent) is shown in the scatter diagram presented in the next section.

3 SCATTER DIAGRAM

After evaluation of the model tests full scale trials performance predictions where the total delivered power was made dimensionless with the admiral coefficient for propulsion: CAD=0.7477 x DISV$^{(2/3)}$ x VS^3 / PD with DISV in m^3, VS in knots and PD in kW, less scatter was found on the basis of the Froude number defined by the length (FNL) than the volumetric Froude number (FNV) based on the speed in metres per second divide by the square root of the acceleration of the gravity (9.81 m/s^2) divide by DISV$^{(1/3)}$.



Based on this diagram an average trend line on the basis of FNL and CAD scatter the following equation is chosen: $y = 13{,}395x^4 - 13{,}378x^3 + 3{,}109x^2 - 108x + 249$ with regression type polynomial order 4.

In the next section these formulas are given in an example calculation.

4 CALCULATION EXAMPLE

SL-ratio =	7.67	(SL-ratio > 7.46 < 8.34)			
Los [m]	124.03	(Los >103.8<142.9 m)			
Eta-shaft	104%				
	Displv				
Displv	4228.6	m3			
	V	FNL	CAD	PD-total	PB per engine
	KNOTS			kW	kW
	5	0.074	253	96	50
	6	0.089	256	165	86
	7	0.103	258	260	135
	8	0.118	261	384	200
	9	0.133	263	542	282
	10	0.148	265	739	384
	11	0.162	266	979	509
	12	0.177	267	1267	659
	13	0.192	267	1610	837
	14	0.207	266	2015	1048
	15	0.221	265	2490	1295
	16	0.236	263	3046	1584
	17	0.251	260	3695	1922
	18	0.266	256	4451	2315
	19	0.280	252	5330	2772
	20	0.295	246	6353	3304
	21	0.310	240	7542	3922
	22	0.325	233	8926	4641
	23	0.339	226	10536	5479
	24	0.354	218	12411	6454
	25	0.369	209	14594	7589
	26	0.384	201	17135	8910
	27	0.398	192	20089	10446
	28	0.413	183	23513	12227
	29	0.428	174	27467	14283
	30	0.443	165	32001	16640
	31	0.457	157	37148	19317
	32	0.472	149	42910	22313
	33	0.487	143	49231	25600
	34	0.502	137	55979	29109
	35	0.516	133	62923	32720

Wageningen, September 2010

MARITIME RESEARCH INSTITUTE NETHERLANDS

APPENDIX I

LIST OF SYMBOLS

Symbol	Symbol in computer print	Title
GEOMETRY OF SHIP AND PROPELLER		
A_{BT}		Transverse cross-section area of bulbous bow
A_E		Expanded propeller blade area
A_E/A_O		Expanded propeller blade area ratio
A_M		Midship sectional area below still waterline
A_O		Propeller disc area
A_T		Transom area below still waterline
A_T/A_M		Transom area ratio
A_W		Waterplane area
A_X		Maximum transverse sectional area below still waterline
B		Maximum breadth moulded at or below still waterline
B_M		Maximum breadth moulded at midship
B_{WL}		Maximum breadth moulded at still waterline
c		Chord length of propeller blade section
c/D		Chord length-diameter ratio
c_{REF}		Chord length between reference line and leading edge
c_t		Chord length between maximum thickness point and leading edge
C_B		Block coefficient
C_M		Midship section coefficient
C_P		Longitudinal prismatic coefficient
C_{WP}		Waterplane area coefficient
d		Hub diameter
d/D		Hub-diameter ratio
D		Propeller diameter
FB		Position of centre of buoyancy aft of FP
f		Camber of propeller blade section
h_o		Submergence of propeller shaft axis measured from still water-plane
h_B		Height of centroid of A_{BT} above keel
i_E		Half angle of entrance
L_{OA}		Length overall
L_{OS}		Length overall submerged
L_{PP}		Length between perpendiculars
L_{WL}		Length on still waterline
LCB		Longitudinal position of centre of buoyancy

Symbol	Symbol in computer print	Title
P		Propeller pitch
P/D		Pitch-diameter ratio
r		Radius of propeller blade section
R		Radius of propeller
S, S_{HULL}		Projected wetted surface bare hull
S_{APP}		Wetted surface area appendages
S_1, S_{TOT}		Total wetted surface area
t		Maximum thickness of propeller blade section
t/c		Maximum thickness-chord length ratio
T		Mean draught moulded
T_A		Moulded draught at aft perpendicular
T_F		Moulded draught at forward perpendicular
Z		Number of blades
λ		Scale ratio
Φ		Pitch angle of propeller section
∇	DISV	Displacement volume moulded

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Symbol	Symbol in computer print	Title
RESISTANCE, OPEN WATER AND PROPULSION		
B_P		Taylor's propeller coefficient
C_A	CA	Incremental resistance coefficient for model-ship correlation
C_{AA}	CAA	Air resistance coefficient
C_{AD}	CAD	Admiralty coefficient for propulsion
CAV N	CAV N	Cavitation influension faktor on rotation rate
CAV P	CAV P	Cavitation influension faktor on power
C_D		Drag coefficient
$C_{D\nabla}$		Power-displacement coefficient
C_E	CE	Admiralty coefficient for resistance
C_F	CF	Specific frictional resistance coefficient
ΔC_F		Roughness allowance coefficient
C_L	CL	Lift coefficient
C_P		Power loading coefficient
C_R	CRES	Specific residual resistance coefficient
C_T	CT	Specific total resistance coefficient
C_{Th}		Thrust loading coefficient
C_T		Resistance-displacement coefficient
C_V	CV	Specific total viscous resistance coefficient
C_W	CW	Specific wavemaking resistance coefficient
F	F	Towing force in propulsion test
F_D	FD	Viscous scale effect on resistance
F_n	FN	Froude number
F_P	PULL	Pull of ship
F_{PO}	PULL	Pull of ship in bollard condition
g		Acceleration due to gravity
J	J	Advance coefficient
J_V	JV	Apparent advance coefficient
1+k	1+K	Three-dimensional form factor on flat plate friction
k_p		Equivalent sandroughness of propeller blade surface
k_s		Roughness height of hull surface
K_Q	KQ	Torque coefficient
K_T	KT	Thrust coefficient
K_{TD}	KT-D	Duct thrust coefficient
K_{TP}	KT-P	Propeller thrust coefficient

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Symbol	Symbol in computer print	Title
n	N	Rate of revolutions
P_B		Brake power
P_D	PD	Power delivered to the propeller(s)
P_E	PE	Effective power
P_I		Indicated power
P_S	PS	Shaft power
P_T		Thrust power
Q	Q	Torque
R	R	Resistance in general
R_n	RN	Reynolds number
R_A		Model-ship correlation resistance
R_F	RF	Frictional resistance
R_{TR}	RTR	Viscous pressure resistance of transom
R_V	RV	Total viscous resistance
R_{VP}	RVP	Viscous pressure resistance
R_W	RW	Wavemaking resistance
s_A		Apparent slip ratio
s_R		Real slip ratio
t	THDF	Thrust deduction fraction
t^*		Thrust deduction fraction from load variation test
T	TH	Thrust
T_D	TH-D	Duct thrust
T_N	TH-N	Nozzle thrust
T_P	TH-P	Propeller thrust
T_U	THU	Thrust of azimuthing thruster unit
V	V	Speed of ship or model
V_A	VA	Advance speed of propeller relative to water flow
V_r	Vr	Radial flow velocity component in the direction of the z-axis of the Pitot tube, and is positive if directed down for strut orientation tests or outward in a wake survey
V_t	Vt	Tangential flow velocity component in the direction of the y-axis of the Pitot tube, and is positive if directed to port for strut orientation tests or in clockwise direction in a wake survey
V_x	Vx	Longitudinal flow velocity component in the direction of the x-axis of the Pitot tube, and is positive if directed aft
w_T	WT	Effective wake fraction on thrust identity
z_V		Sinkage due to speed

Symbol	Symbol in computer print	Title
β		Advance angle of propeller blade section
η_B		Propeller efficiency behind ship
η_D	ETA-D	Propulsive efficiency
η_G		Gearing efficiency
η_H	ETA-H	Hull efficiency
η_M		Mechanical efficiency
η_o	ETA-O	Propeller efficiency in open water
η_R	ETA-R	Relative-rotative efficiency on thrust identity
η_S		Shafting efficiency
ν		Coefficient of kinemetic viscosity
ρ		Mass density
τ		Ratio propeller thrust and total thrust of ducted propeller system
$-_m$	$-_M$	Subscript for model
$-_o$	$-_O$	Subscript for open water
$-_s$	$-_S$	Subscript for ship